Curing and Storage of
Tropical Roots, Tubers and Corms
to Reduce Postharvest Losses

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1. Introduction

The underground, starchy crops which include cassava, potato, sweet potato, yam, taro and *Xanthosoma* (see Table 1 for the alternate names) are loosely referred to as 'root' crops, although they are botanically diverse and the edible structures can be roots, tubers, corms or cormels (Table 1).

Table 1. Names and botanical structure of the important tropical 'root' crops.

Name	**Other names**	**Latin name**	**Family**	**Plant part**
Cassava	manioc, yucca, mandioca, Brazilian arrowroot, tapioca, garri	*Manihot esculenta*	Euphorbiaceae	root
Potato	Irish potato, white potato	*Solanum tuberosum*	Solanaceae	tuber
Sweet potato (sweetpotato*)	yam, taino, batata, camote, kamote, kumara	*Ipomoea batatas*	Convolvulaceae	root
Yam	Ñamé, igname	*Dioscorea species*	Dioscoreaceae	tuber
	greater yam or water yam	*D. alata*		
	lesser yam or Chinese yam	*D. esculenta*		
	white yam	*D. rotundata*		
	yellow yam	*D. cayenensis*		
	trifoliate yam	*D. dumetorum*		
	aerial yam	*D. bulbifera*		
	Chinese yam or cinnamon-vine	*D. batatas*		
	cush-cush yam	*D. trifida*		
Taro	cocoyam or old cocoyam, eddo(e), malanga, gabi, Abi, tales, ndaloi, talo, colcas, kalo, dasheen, Kolkas, gabi, amadumbe	*Colocasia esculenta*	Araceae	corm
Xanthosoma	cocoyam or new cocoyam, malanga, tanier, tannier, tannia, yautia, Chinese taro, badoo, macabo	*Xanthosoma sagittifolium*	Araceae	cormel

*in 1989 the Sweetpotato Collaborators of USA changed the spelling to 'sweetpotato'

Global production of these root, tuber and corm crops is about 836 million tonnes from 60 million hectares of land (Table 2) (FAOSTAT, 2016). The relative importance of these crops to the regions is also indicated in Table 2. Potato, the only temperate crop, is the most widely produced of these crops (in tonnes) and is important throughout the world, particularly in Asia and Europe. The other root crops are tropical in origin and are an important dietary staple in developing countries.

Postharvest losses of these root and tuber crops can be can be exceptionally high, and range from 10% to as high as 65%. Typically the starchy root vegetables have a relatively high moisture content (50-70%) and a high respiration rate. Most of the postharvest losses are attributed to weight loss, which is predominantly from water loss, and decay. They are also susceptible to pest damage and sprouting which can reduce quality. In cassava, however, a physiological disorder limits storage life considerably and is responsible for the majority of the postharvest losses.

Although the edible portion of these crops are derived from different plant parts (Table 1) they are all able to heal their wounds and develop physical protection. This is achieved through a process known as curing which encourages wound healing and suberin and/or lignin deposition (Lebot, 2009; Rees et al., 2012). Curing is universally practiced for potato, and for the other starchy root crops grown in temperate areas. But despite high postharvest losses of the tropical root crops curing is generally not practiced. Incidental curing can, however, occur under moderate temperatures and high relative humidity (van Oirschot et al., 2003; van Oirschot et al., 2006; Atuna et al., 2016).

Table 2. Area harvested (A) and production (B) of the starchy underground, or root, crops and their relative proportions in each region of the world (compiled from FAOSTAT, 2016).

A. Crop	**Area harvested (ha)**	**Area harvested by region (%)**				
		Africa	**Americas**	**Asia**	**Europe**	**Oceania**
Cassava	23,482,052	72.4	9.7	17.8	0	0.1
Potato	19,246,462	9.2	9.2	52.9	28.5	0.2
Sweet potato	8,623,973	48.6	4.2	45.4	0	1.8
Yam	7,454,583	97.4	2.0	0.1	0	0.5
Taro	1,669,708	88.1	0.5	8.1	0	3.3
Xanthosoma	40,163	0	100.0	0	0	0

B. Crop	**Production (tonnes)**	**Production by region (%)**				
		Africa	**Americas**	**Asia**	**Europe**	**Oceania**
Cassava	277,102,564	56.8	10.9	32.2	0	0.1
Potato	376,826,967	6.5	11.3	50.6	31.2	0.4
Sweet potato	105,190,501	20.3	4.1	74.7	0	0.9
Yam	65,937,599	97.0	2.1	0.3	0	0.7
Taro	10,128,954	72.8	0.7	22.3	0	4.2
Xanthosoma	478,950	0	100.0	0	0	0

The objective of this white paper is to highlight postharvest losses of the tropical root crops and point out the advantages associated with curing, as well as describing various curing and storage systems and conditions. Potato is mainly included for reference as the review focusses on the tropical root crops.

2. Curing

Curing is the process of wound healing, suberization or lignification, and the formation of new tissue beneath the surface of injured areas in these crops. Curing results in reduced water loss, greater resistance to decay, and longer storage life.

There are several steps involved in wound healing during curing, specifically:

1. desiccation of several layers of surface cells at the site of the wound;
2. thickening of cell walls below the wound and deposition of suberin (suberization) and/or lignin (lignification);

3. formation of new cells called wound periderm below the suberized layer.

Suberin and lignin help to 'waterproof' cells and reduce water loss. These compounds also reduce the susceptibility to fungal pathogens. The wound periderm forms more quickly under curing conditions but will continue to grow in storage once lignification has occurred. The thickness of this cell layer depends on genotype and varies from about 4-10 layers (Walter & Schadel, 1982; van Oirschot et al., 2003).

Photographs of curing in sweetpotato can be viewed in Chapter 6 (van Oirschot et al., 2002; http://gala.gre.ac.uk/12129/1/12129_McBride_Sweet%20potato%20post%20harvest%20%28pub%20PDF%20OA%29%202002.pdf.).

Curing conditions for the different root crops are summarized in Table 3 and crop specific recommendations are covered in Section 5. In general, warm temperatures (30-40°C) and high relative humidity (>85% RH) with good ventilation (for removal of carbon dioxide and replenishment of oxygen) is recommended for curing tropical roots (Ravi et al., 1996; Eshel, 2011). Curing usually takes 4-10 days but longer times are when temperature and relative humidity are not ideal.

Curing of crops should begin as soon after harvest as possible, preferably within 12 hours of harvest. Roots, tubers and corms should not be washed prior to curing and/or storage as this increases decay. If necessary roots can be washed prior to marketing (Edmunds et al., 2008; Eshel, 2011).

Table 3. Conditions for curing root crops (compiled from this white paper).

Commodity	Temperature (°C)		Relative Humidity (%)	Duration*
	Optimum range	Acceptable range	Optimum range	(days)
Cassava	30-35	25-40	80-95	7-14
Potato	10-15	7-15	85-95	10-14
Sweet potato	28-30	30-32	85-90	3-10
Taro	34-36	30-36	85-98	3-5
Yams	30-35	25-35	85-90	4-15
Xanthosoma	30-35	25-35	90-98	5-10

*Curing takes longer outside of the optimum temperature range and at lower RH.

3. Tests to evaluate curing

A simple test for curing is to feel the peel of the crop. If the peel is firmly attached and does not 'slip' when pressed sideways the root has cured (Kitinoja & Kader, 2015). A more quantitative measure of curing can be made by staining thin cross sections of the root for lignin (1% phloroglucinol in 95% ethanol for 2 min, followed by 30 s in concentrated HCl, and rinsing in water). The pink to brown color development is rated under a microscope on a scale between 0 and 1 (Table 4). The average rating from four sections is called the lignification score (Walter & Schadel, 1982; van Oirschot et al., 2002, 2003, 2006).

Atuna et al. (2016) created wounds in sweet potato roots using a potato peeler and used a similar test with phloroglucinol to evaluate wound healing, Photographs of stained sweet potato can be viewed at http://www.sweetpotatoknowledge.org/files/wound-healing-and-dry-matter-of-orange-fleshed-sweetpotato-cultivars-as-influenced-by-curing-methods/.

Table 4 Scores for lignification of sweet potato wound sections representing continuity of lignified layer (van Oirschot et al., 2003).

		Completeness of lignin layer		
Description of lignification	**Lignification score**	**Presence of lignin**	**Completeness of lignification**	**Distribution of lignin in the wound**
Complete	1	1	1	
Patchy	0.5	1	0	
None	0	0	0	

4. Curing systems

Various methods of curing root crops have been used. They vary in their efficacy and cost of implementation.

Pre-harvest in-ground curing or field curing is where root vegetables are not harvested but are left in the field after leaf removal (pruning, dehaulming) in the hot, humid times of the year and curing takes place in situ. This is neither a reliable form of curing nor an efficient use of land, however, it has been shown to reduce postharvest losses (Stathers et al., 2013).

Mound or heap curing involves stacking or mounding the crops, covering them with a thick layer of sand, cut grass, or straw for insulation, and then placing sacks, jute bags or canvas tarpaulins over the mounds (Figure 1, 2a). This creates warm and humid conditions. Plastic covers are not usually used as the mound can easily become too hot and damage the root crop. The mounds should be left for the recommended duration of curing (Kitinoja & Kader, 2015).

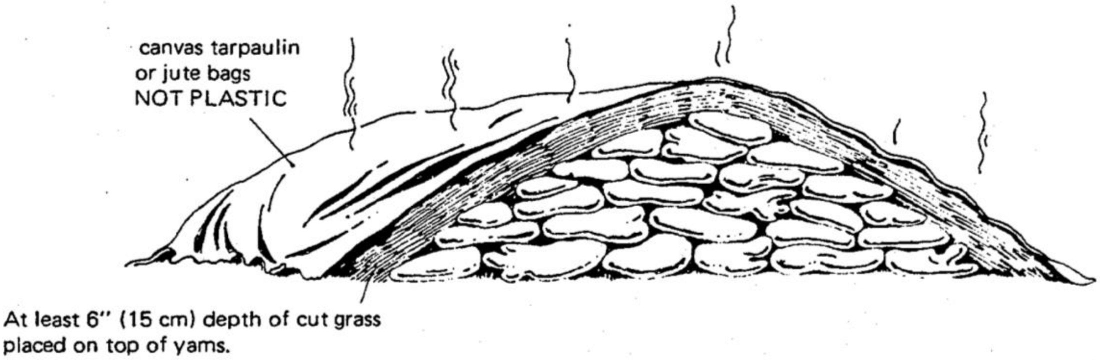
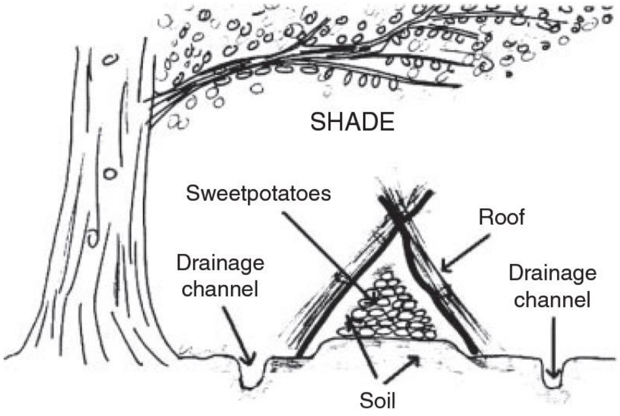


Figure 1. A cut away view of yam curing in covered mounds or piles (Kitinoja & Kader, 2015; original source: Wilson, J. Undated Careful storage of yams: Some basic principles to reduce losses. Commonwealth Secretariat, London/International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria).

A modification of mound curing is a field clamp. In this case the mound is built around a bucket of water and can be covered with a plastic sheet (Bancroft et al., 2005).

Pit curing is where a hole is dig and lined with wood shavings, cut grass, straw, sand or soil (Figure 2) (Rees et al., 2012). The root crops can be cured in these pits for up to 15 days before being transferred to storage sheds (Nnodu, 1986) or stored in the pits for several weeks (van Oirschot et al., 2007)

(a) Heap store



(b) Pit store

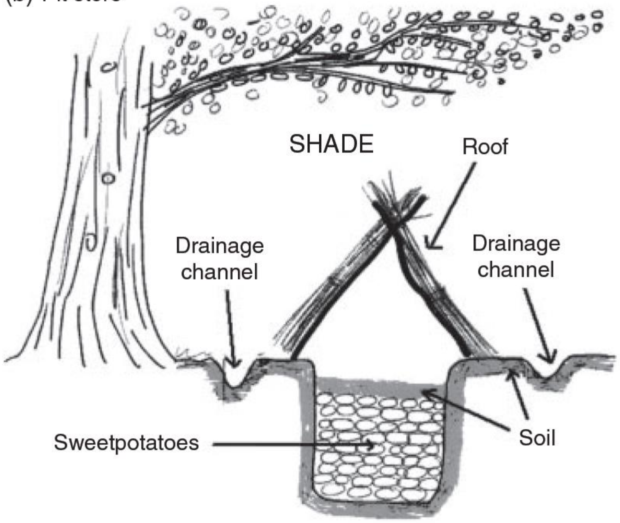


Figure 2. Construction of heap and pit stores used for curing or storage (Rees et al., 2012).

Shed or barn curing is preferred and, in the simplest form it may consist of a covered shed in warm areas with high humidity. The covering can be locally available material e.g. thatch grass or palm leaves. The root crops should be placed on shelves or in sacks (not plastic) and allowed to cure. Sheds with sides can also be used and ideally sheds should have an exhaust fan for ventilation (Figure 3) (Kitinoja & Kader, 2015).

Evaporatively cooled structures e.g. a zero energy cool chamber (ZECC) (Figure 4), can be used to create warm and humid conditions for curing in very hot regions. Sajeev et al. (2004) used an evaporatively cooled structure to create conditions of 26-34°C, with 59-92% RH. In more moderate climates the ZECC could be modified with a black plastic cover to increase the temperature and still maintain high humidity.

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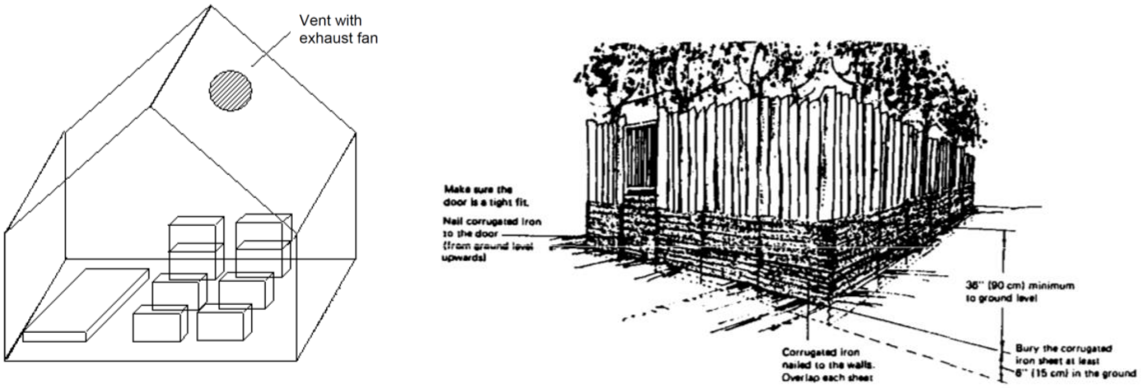

Figure 3 Curing of root crops in (A) a shaded, ventilated shed (Kitinoja & Kader, 2015) or (B) a yam barn with a rodent proof fence (Wilson undated).

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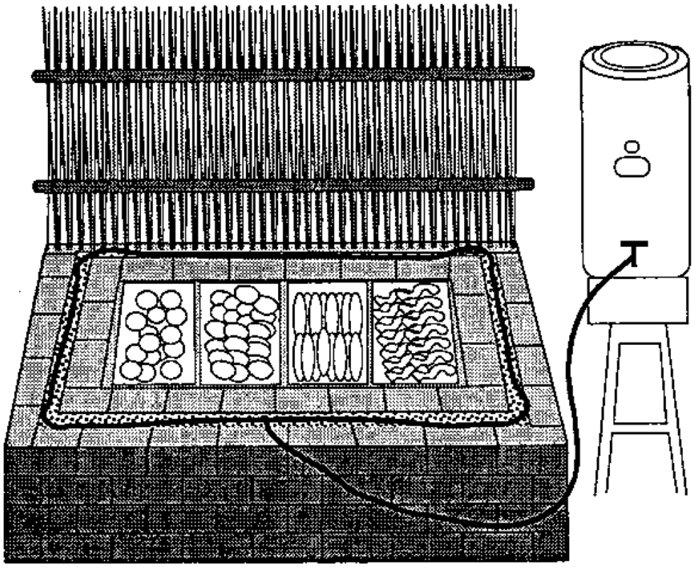

Figure 4. Improved zero energy cool chamber (ZECC) (Roy, 1989).

Controlled environments i.e., insulated rooms with temperature and humidity control are ideal for curing root crops because they can maintain a constant consistent temperature and humidity (Figure 5). The roots can be placed in bulk bins, or packed in smaller boxes in pallets or on shelving (Thompson & Scheuerman, 1993; Kitinoja & Kader, 2015)

The more advanced curing and storage facilities use negative horizontal ventilation where fans mounted in a plenum create a negative pressure which draws the air horizontally past the storage containers. The return air moves back over the top of the stacked containers. This type of air flow results in a very uniform temperature and humidity throughout the room. The air in these storage rooms is heated to the ideal curing temperatures and once curing is complete the room is cooled and maintained at the ideal storage temperature (Edmunds et al., 2008).

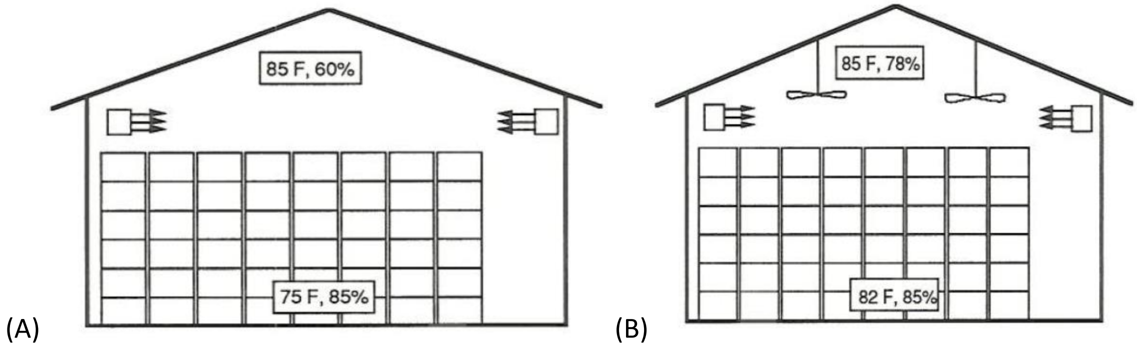

Figure 5 Curing room with top mounted heaters (A) and with ceiling fans (B). Numbers in boxes are the typical air temperature and relative humidity at those locations (75°F=23.9°C; 82°F=27.8°C; 85°F=29.4°C) (Thompson & Scheuerman, 1993).

5. Crop specific details

5.1 Cassava

Cassava (*Manihot esculenta*) is widely grown around the world except in Europe (Table 2). The largest producer is Nigeria, followed by Thailand and Brazil. Yields tend to be lower (<10t/ha) in many African countries including several of the top producers e.g. Nigeria, Democratic Republic of Congo, Mozambique and Tanzania (FAOSTAT, 2016).

Cassava tends to be more perishable than other major root crops and can be unacceptable within 2-3 days of harvest (Morante et al., 2010). A survey of farmers in Ghana found that on average it took 3 days for cassava roots to deteriorate after harvest (Prempeh et al., 2017). The reason for cassava's high perishability is postharvest physiological deterioration (PPD). This causes a blue-black discoloration of the vascular tissue that progresses to general discoloration of the root and decay. PPD begins 1-3 days after harvest at 20-30°C and 65-80% RH (Morante et al., 2010; Prempeh et al., 2017)

A review on 'Cassava post-harvest physiological deterioration: From triggers to symptoms' was recently published (Zainuddin et al., 2018). Essentially the wounding of the roots during harvest triggers a complex enzymatic response resulting in the production of reactive oxygen species, conversion of starch to sugar, accumulation of secondary metabolites (e.g. phenolics compounds and terpenes) and eventually discoloration of the vascular tissues. Water stress, increased respiration, oxygen, and presence of ethylene all contribute to higher PPD.

Postharvest losses

Postharvest losses differ considerably between areas of production, cultivars and storage conditions. Losses of 17-24% have been reported in the Dominican Republic, and about 10% in Brazil and Indonesia (Ravi et al., 1996 and papers cited within). Loss estimates are about 10-12% in India and 3-6% in Indonesia. Older, poorer quality tubers sell at lower prices, resulting in economic losses in addition to the direct postharvest losses (Wenham, 1994). A recent assessment of postharvest losses of cassava in Nigeria demonstrated high levels of losses along the handling chain (Figure 6) (AGRA, 2014).

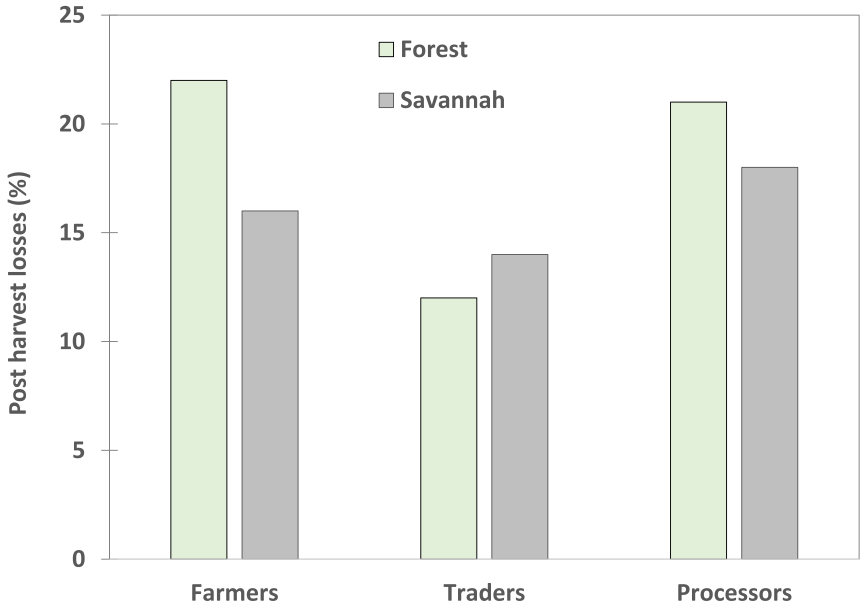

Figure 6. Postharvest losses of cassava produced in the forest and savannah regions of Nigeria (redrawn from AGRA, 2014).

Table 5. Postharvest physiological deterioration (PPD), total carotenoid content (TCC) and dry matter content (DMC) of cassava roots (Morante et al., 2010). (Refer to article for statistical significance of these data).

	PPD (%)				TCC	DM
Clone	**5 days**	**10 days**	**20 days**	**40 days**	**ug/g**	**(%)**
CM 523-7	27.1	40.7	57.1	64.1	0.4	44.8
MCol 1505	25.7	31.6	71.6	66.4	0.7	40.1
Waxy 7	18.2	31.1	30.4	30.4	1.0	40.0
BC284-42	16.8	14.1	16.0	na	0.7	40.5
CW 429-1	12.5	20.7	23.2	18.6	0.6	37.2
MPer 183	5.4	4.0	5.3	9.2	0.5	41.3
BC284-49	4.7	4.8	23.3	na	2.5	27.4
Waxy 2	3.7	8.0	3.6	3.6	0.6	35.6
CB 7-9	3.6	10.9	0	1.0	10.2	35.8
Waxy 6	3.4	1.4	4.7	2.2	0.5	36.1
5G108-4	2.9	3.7	7.1	7.3	0.7	45.4
MBra 253	1.0	0	2.9	0	9.5	42.0
2G15-1	0.5	0	0	6.9	1.0	44.0
CB 44-15	0.5	0	1.0	1.0	11.5	19.5
Waxy 3	0.2	0	3.7	6.8	0.5	42.2
MCol 2436	0	26.3	38.9	na	9.1	34.6
AM 206-5	0	0	0	0	0.7	38.5
BC289-30	0	1.0	0	0	0.5	34.5
GM 905-66	0	0	0	0	11.1	38.3
Waxy 4	0	0	0	0	0.6	36.2
Waxy 5	0	0	4.1	0	0.9	40.2
Average	6	9.4	13.9	12.1	2.8	39.9

Some genotypes of cassava are more tolerant of PPD and had no symptoms after 40 days of storage in an open shed, while other varieties had up to 66% of their roots affected (Table 5). In this study the average PPD at 40 d (12%) appeared to be slightly lower than at 20 d 14%) because roots of several genotypes had rotted and the PPD severity could not be assessed (Morante et al., 2010).

After 14 days of storage at ambient conditions in an open shed in Colombia roots from the susceptible cultivar (HMC-1) had 35% PPD while the tolerant genotype (AM 206-5) had only 8%. Weight loss was about 10% in both clones (Sanchez et al., 2013). Tumuhimbise et al. (2015) found considerable differences in PPD of 12 genotypes after 7 days of storage in a well ventilated room at 23-28°C and 70-80% RH (Table 6).

Zainuddin et al. (2018) reviewed the financial impact of PPD in cassava: Extending the storage life of cassava in Thailand to 45 days was estimated to increase annual benefits by approximately US$35 million (Vlaar et al., 2007; Garcia et al., 2013). Delaying PPD was estimated to be worth to US$2.9 billion in Nigeria, $855 million in Ghana, and $280 million in Uganda, over a 20 year time period (Rudi et al., 2010).

Table 6. Postharvest physiological deterioration (% PPD after 7 days of storage) and dry matter content at harvest of 12 cassava genotypes averaged across three locations and five harvest dates in Uganda (adapted from Tumuhimbise et al., 2015).

Genotype	PPD (%)	DMC (%)
Bukalasa 11	62.1	36.9
FS7-18	51.4	35.3
TMS192/0067	47.5	30.1
TME14	42.5	35.3
MM96/4271	40.2	31.2
FS37-4	38.6	33.0
FS27-15	37.4	31.6
FS1-4	35.2	30.9
Nyaraboke	30.3	30.0
SS4	28.7	31.1
FS25-5	28.2	31.5
TMS30572	25.2	26.8
Mean	38.9	32.0

Benefits of curing

Cassava roots can be cured but the process takes longer than for other tropical root crops (Rees et al., 2012). Booth (1976) found that curing suppressed PPD and reduced postharvest losses. The weight loss of cured and uncured roots was 8.3% and 16%, respectively, after 11 days of storage at 24°C. After 4 days of storage most of the uncured roots were unacceptable while after 7 days 80% of the cured roots were acceptable. However when cured roots were damaged deterioration was as rapid as for uncured roots (Booth, 1976).

In a recent survey of farmers' knowledge and practices in Ghana there was no mention of curing as a means to extend the storage life of cassava, even though 68% of the farmers stored the root (Prempeh et al., 2017). The focus in reducing postharvest losses has been on breeding and selecting for genotypes that are more tolerant of PPD (Prempeh et al., 2017).

Curing Conditions

Cassava roots are able to heal wounds at high humidity (80-95% RH) but require 7-9 days at 35°C or even longer (10-14 days) at 25°C. Formation of periderm was even more rapid at 40°C but the risk of deterioration was higher (Booth, 1976; Rickard, 1985).

A curing bag is being developed for curing cassava roots http://www.iita.org/news-item/the-rockefeller-foundation-announces-results-of-the-cassava-innovation-challenge and more results on that will be published soon.

In-ground curing, i.e. pruning the foliage 3 weeks prior to harvest can slightly reduce harvest damage (van Oirschot et al., 2000).

Storage recommendations

Storing roots at 10°C and 80% RH can delay the onset of deterioration by 14 days (Booth 1976; Morante et al., 2010). Although cassava is chilling sensitive it can be stored at 0-5°C and 85-90% RH for 1-2 months with minimal symptoms (Cantwell, 2002).

Prempeh et al. (2017) found that 68% of the 137 farmers surveyed in Ghana stored their cassava and they used different storage methods (Figure 7). Storage in polythene and jute sacks delayed PPD for a few days.

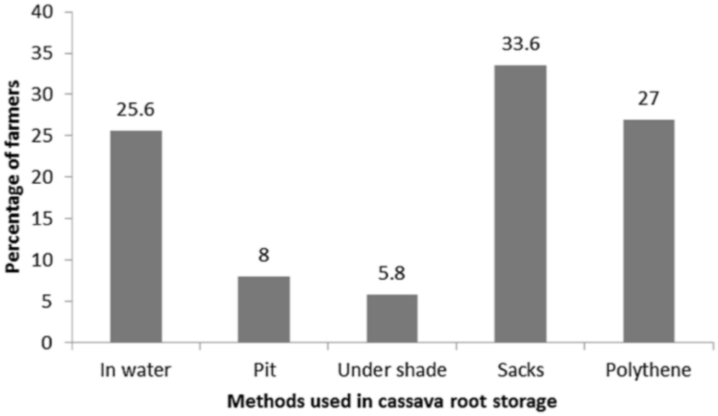

Figure 7. Methods of storing cassava roots after harvest and the relative proportions of farmers using each method (Prempeh et al., 2017).

Cassava roots are often left in the soil until needed to extend their storage life, however the roots are susceptible to decay and become more fibrous (Lancaster & Coursey, 1984). Nduwumuremyi et al., (2016) reported that 72% of farmers surveyed in Rwanda delay the harvest of cassava for more than one year. Most farmers surveyed in Rwanda found that cassava roots can be stored underground for only 4 days (Nduwumuremyi et al., 2016). Roots can also be stored in piles covered in soil but shelf life is still only days (Ravi et al., 1996). There is a report of cassava being stored in trenches in the ground for up to 9 months but the flavor tended to be poorer (Ravi et al., 1996).

5.2 Sweetpotato

Sweetpotato *(Ipomoea batatas)* is grown throughout the world except for Europe (Table 2). This crop is particularly important in Asia and Africa with China being the largest producer followed by Nigeria and Tanzania (FAOSTAT, 2016).

Freshly harvested sweetpotato roots are very susceptible to water loss because they have a thin delicate skin that is easily damaged and a relatively high moisture content (60-70%) (Edmunds et al., 2008). The respiration rate is high and the roots are very susceptible to fungal or bacterial decay. Rees et al. (2001) found that sweetpotatoes have a shelf life of 1 to 2 weeks during marketing in East Africa while properly cured sweetpotatoes stored in ideal conditions can be kept for many months (Edmunds et al., 2008).

Postharvest losses

Sweetpotato losses in the USA are estimated to be 20-25% during curing and storage, 5-15% during shipping and retail, and 10-15% at the final consumer (Edmunds et al., 2008). Estes et al. (1989) measured 13.6 to 22% unacceptable damage and 0.2 to 2.5% weight loss in sweetpotatoes shipped from packing sheds to retails stores.

Estimates of postharvest loss of sweetpotato in the tropics varied from 20-77% (Table 7) (Ray & Ravi, 2005). The postharvest losses of sweetpotato are mainly attributed to water loss and decay during storage but sprouting, poor eating quality and pest damage are also important (Table 8) (Rees et al., 2003a,b). Acceptable weight loss is 5 to 8% (Edmunds et al., 2008).

When Rees et al. (2003a) purchased sweetpotato from markets in Tanzania and stored them under simulated marketing conditions they found very high weight loss and decay (Figure 8). They also found significant pest damage (up to 93% damage with 44-67% being severe damage), particularly from larvae of sweet potato weevils *(Cylas* spp.).

Cultivars differ in their susceptibility to both water loss and decay. ‘Mwanamonde’ lost 31% water during 14 days of storage versus only 8% in ‘Bilagala’. Cultivars that had higher rates of water loss also tended to be more susceptible to decay Rees et al. (2003a, b). These researchers also found greater weight loss when roots were damaged, particularly during the first week of storage (Figure 9) (Rees et al., 2001; Rees et al., 2003a). Further details on these Tanzanian cultivars are available in chapter 5 of their report:
http://gala.gre.ac.uk/12129/1/12129_McBride_Sweet%20potato%20post%20harvest%20%28pub%20PDF%20OA%29%202002.pdf

In Tanzania the handling and transport of sweetpotatoes resulted in 20% of the roots being severely broken and 86% of the roots being skinned, reducing the market value by 13% (Tomlins et al., 2000). Retailers in Tanzania sell most of their sweet potato supplies within 7 days of receipt (Kapinga et al., 1997).

Table 7. Sweetpotato losses, and causes of those losses, when stored in the tropics with different methods (Ray & Ravi, 2005 - for specific references see original paper).

Storage methods	Storage period (weeks)	Loss (%)	Causes
Bamboo lined pit under thatched roof	8	22 82	Weight loss Sprouting
Clamp lined with grass under thatched roof	8	22 77	Weight loss Sprouting
Clamp	12-20	30	Weight loss, rotting
Pits in open area/corner of house covered with straw	24	<20	Weight loss, rotting
Simulated pit conditions in laboratory	8	50	Rotting
Pits with alternate layers of wood ash	4-8	20-40	Weight loss, rotting, sprouting
Heap storage	8-16	20-25	Rotting, weevils
Roots piled on bench made of bamboo	8-16	20-25	Weight loss, rotting, rodents, weevils
Trench 50 cm deep, covered with sand, sheltered by a rood	7	35 45	Rotting Sprouting Weevils
Sand	6-7	<30	Weight loss
Closed cardboard cartons covered with grass	-	29-35 5-44	Weight loss Sprouting

Table 8. Forms of deterioration of sweet potato storage roots (Rees et al., 2003a).

Reason	Response
Weight loss	Roots can lose weight both by losing water, and also by metabolizing the starch reserves through the process of respiration. Under normal marketing conditions most weight loss (90%) is through water loss (Van Oirschot et al., 2000; Rees et al., 2008. Water loss causes the root to become less attractive as it shrivels and, as described below, also appears to make the root more susceptible to rotting.
Rotting	Rotting of tissues occurs by both fungal and bacterial pathogens. When rotting starts a root quickly becomes unsaleable
Sprouting	When a root sprouts, it will often become sweeter as starch is converted to sugar to provide energy for the growth of sprouts. The appearance of sprouts and loss of starch reduces the root value.
Loss of good taste	Many changes can occur in the root composition after harvest, which may affect the taste and texture of the cooked root.
Infestation by insects	The most important insect pest of the storage root is the sweet potato weevil (*Cylas* spp.). Even if infestation is only slight, then the root can become completely unsaleable due to the production of bitter tasting phytoalexins as part of the defence mechanism of the root.

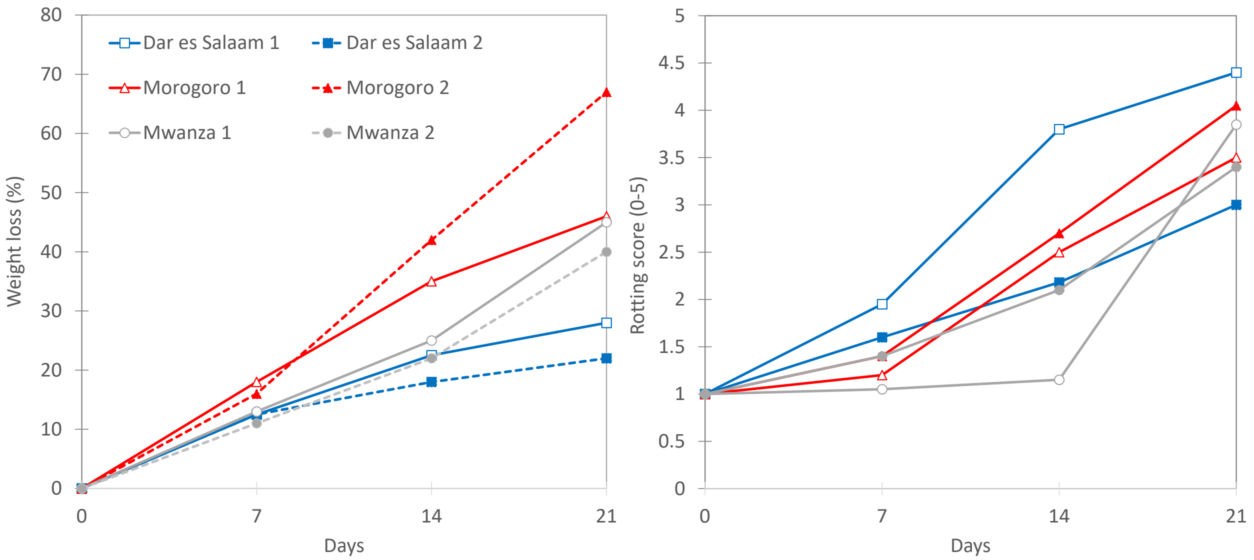

Figure 8. Rates of weight loss (%) and decay or rotting score (0-5; where 0=0% visible rot; 1=1-10%; 2=11-25%; 3=26-50%; 4=51-75%; 5=76-100%) for three varieties of sweet potatoes purchased at markets and stored under simulated marketing conditions (where 1= low season 1; 2= low season 2) (Rees et al., 2003a).

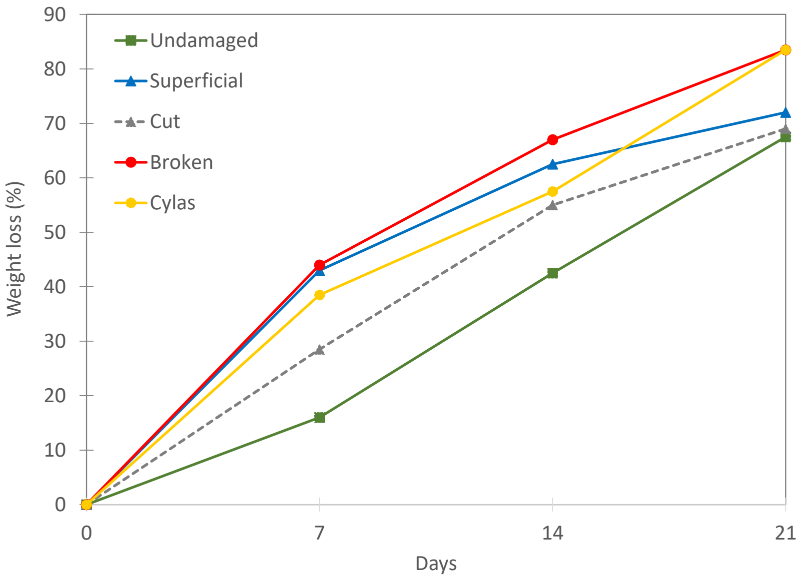

Figure 9 The effect of root damage on the rates of root weight loss in ‘Morogoro’ sweet potato during low season 2 (Rees et al., 2003a).

When sweetpotato roots were stored under humid conditions in lined, closed sacks decay scores differed between the cultivars evaluated with ‘Budagala’ being the most resistant and ‘SPN/O’ being the most susceptible (Figure 10) (Mbilinyi *et al.,* 2000; Rees et al., 2003a).

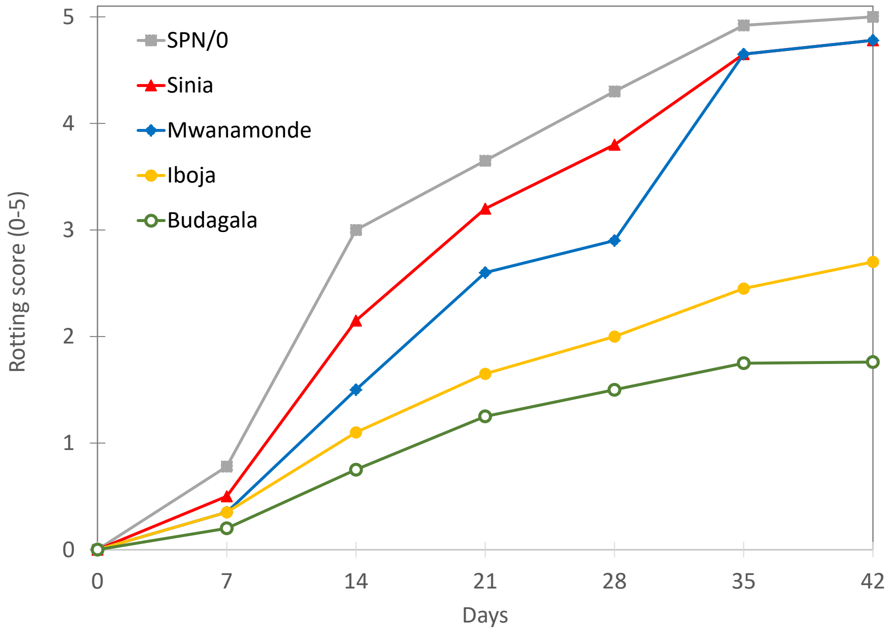

Figure 10. The rotting score (0-5 see Figure 8 for details on score) for five key Tanzanian cultivars stored for up to 42 weeks under high humidity in lined, closed bags (Mbilinyi *et al.,* 2000; Rees et al., 2003a).

Benefits of Curing

Curing of sweetpotatoes has many benefits. It heals the wounds incurred during harvesting reducing subsequent water loss and decay during storage and allows sweet potatoes to be handled more easily (Edmunds et al., 2008). Proper curing improves sensory qualities by decreasing starch content, increasing sugars and enhancing aroma (Edmunds et al., 2008).

The process of curing causes water loss but subsequent water loss during storage is reduced. Cured and uncured 'Garnet' sweetpotato lost 4.6 and 4.8% of their weight, respectively during a 5 day curing period but thereafter cured roots lost 1.7% and uncured roots lost 2.6% of their initial weight per month during for 6 months storage under commercial conditions in California (Thompson & Scheuerman, 1993). Uncured sweetpotatoes stored for 113 days lost 42% of their weight while cured sweetpotatoes only lost 17% (Booth, 1974).

Curing of 'Georgia Jet' resulted in only 8% decay after 6 months of storage at 14°C while uncured roots had 47% decay. The pack out (i.e. saleable roots) of cured 'Garnet' sweet potato was 42% compared to only 18% in uncured roots after six months of storage (Thompson & Scheuerman, 1993).

Curing conditions

Sweetpotato can be cured at 27-32°C and 75-95% RH for 3-10 days. The recommendations for curing sweetpotatoes under environmentally controlled conditions in the USA are 29°C and 85-90% with proper ventilation for 3-5 days immediately after harvest. The duration of curing increases if the difference between the root pulp temperature at harvest and the curing temperature is large. However excess time under curing conditions encourages sprouting (Edmunds et al., 2008).

Stathers et al. (2013) outlined a curing method developed in India where freshly harvested roots in a well ventilated area were covered with a polythene sheet raised about 15-20 cm above the layer of roots during the day. The sheet was removed each night. Several days of this curing process led to increased shelf life of the sweet potato roots and reduced decay.

‘In-ground’ curing i.e. removing sweetpotato stems and leaves 7 to 14 days before harvesting can reduce postharvest losses by up to 40% (Abong et al., 2016; Atuna et al., 2016). Stathers et al. (2013) stated that (dehaulming) of sweet potato plants can take place up to 2-4 days before harvesting. Atuna et al. (2016) found that mounding or field-piling ‘Apomunden’ and ‘Nane’ sweet potatoes and covering them with vines for 7 days was slightly more effective at curing than pruning 7 days before harvest based on the lignification scores (0.85 and 0.75, respectively).

The difference in the curing ability of sweetpotato cultivars can be measured by their lignification score (Figure 11). The difference in curing ability was minimal at 25°C and very high relative humidity (97% RH) but becomes more pronounced at lower humidity (65% RH and 58% RH) which occur when curing is not under controlled environments (van Oirschot et al., 2003, 2006). Selection of varieties that cure more rapidly at lower RH is recommended where the curing conditions cannot be precisely controlled.

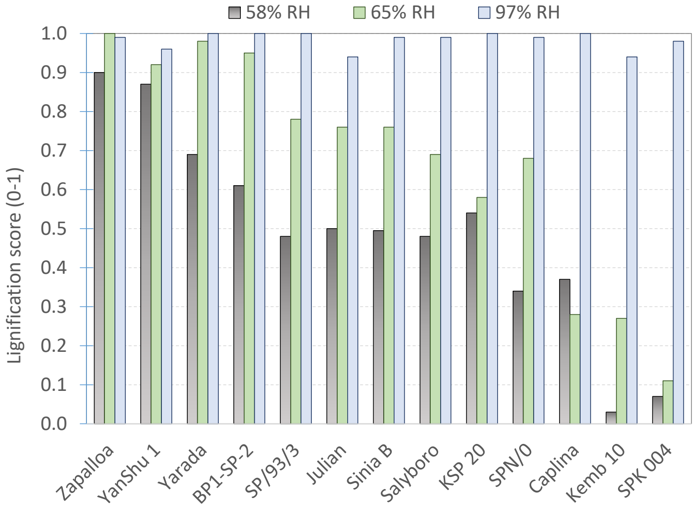

Figure 11. The lignification score (average of score at 3 and 6 days) of 13 sweet potato cultivars measured after healing at three levels of relative humidity (58%, 65% and 97) (redrawn from van Oirschot et al., 2006).

Low dry matter and high sugar levels of sweetpotato roots are associated with longer storage life and more efficient wound healing at lower humidity (Rees et al., 2003b, 2008; van Oirschot et al., 2002, 2006). The differences in curing between cultivars is related to these levels (Rees et al., 2008).

Storage recommendations

Roots intended for storage should be properly cured immediately after harvest and preferably within 12 hours. Sweet potatoes are chilling sensitive and ideal storage conditions are 13-15°C and 80-95% RH with good ventilation (Cantwell, 2002; Edmunds et al., 2008). Under these conditions sweet potatoes have been stored for up to 13 months (Edmunds et al., 2008). Temperatures above 15°C lead to more rapid sprouting and weight loss. Lower relative humidity (>70-90% RH) is acceptable for short-term storage or during marketing (Cantwell & Suslow, 2001).

Sweetpotato roots in USA are often stored in evaporatively cooled rooms during the cooler months. This is supplemented by mechanical refrigeration later in the storage period when ambient temperatures increase (Figure 12) (Thompson & Scheuerman, 1993; Cantwell & Suslow, 2001).

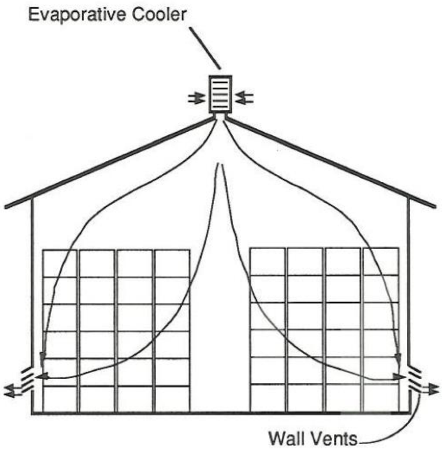

Figure 12. Air flow in an evaporatively cooled storage room (Thompson & Scheuerman, 1993).

Sweetpotatoes tend to have a short shelf life (7-14 days) when being marketed in tropical developing countries, mainly because of high levels of weight loss and decay. The weight loss, determined to be predominantly (86%) water loss, promoted decay (Figure 13). Low dry matter was associated with high weight loss and decay (Rees et al., 2008).

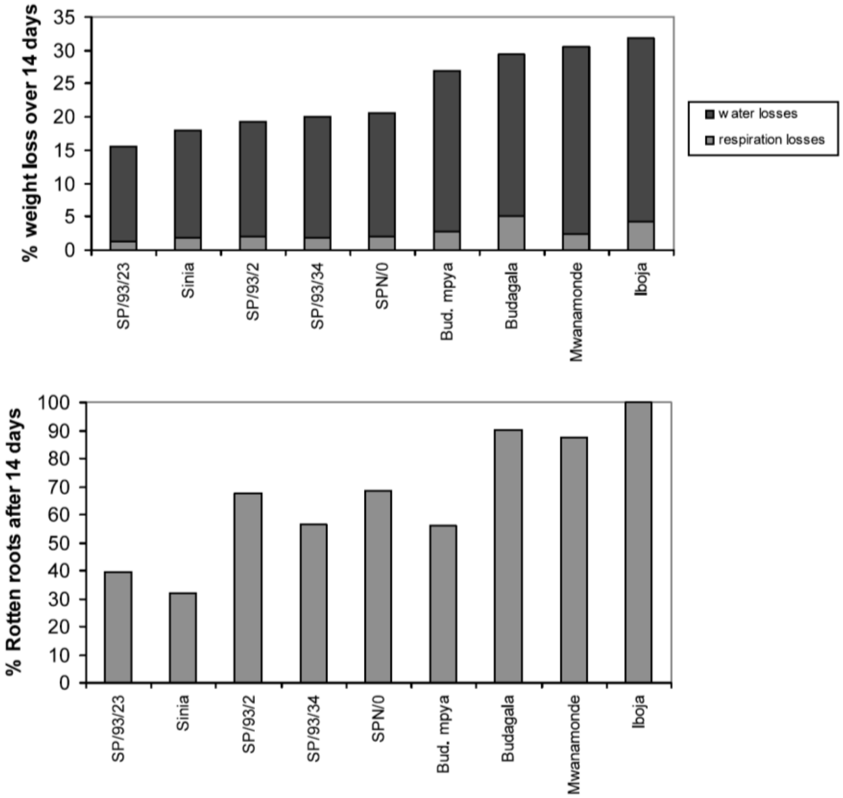

Figure 13. Weight loss (with estimated contribution from water loss and respiration) and rotting for sweet potato cultivars during storage under simulated marketing conditions (Rees et al., 2008).

Van Oirschot et al. (2007) evaluated different storage design factors over an 18 week storage period. This evaluation included 36 different variables using traditional pit and heap/clamp stores (Figure 2), three cultivars, different levels of damage to the roots, varying ventilation and storage areas lined with grass and both pit and clamp store designs over 18 weeks and found several of these factors affected the various postharvest quality parameters measured (Table 9).

Table 9. Storage design factors that had a significant effect ($P < 0.05$) upon physiological changes of the roots during storage in on-station trials in the Lake Zone of Tanzania (from van Oirschot et al., 2007).

Physiological changes	Store design factors with significant effect	Design effects on physiological changes
Weight loss	Lining with grass Clamp/pit	Lower weight loss when stores were not lined. Store type affected weight loss in week 8
Dry matter (DM) of cooked roots	Lining with grass Cultivar	Lower DM when stores were not lined 'Polista' had the highest DM ($P<0.05$; 41-44% compared to 37-41% in other cultivars)
Dry matter (DM) of raw roots (uncooked)	Cultivar	'Polista' had the highest DM
Oxygen (O_2) in the air within the store	Cultivar Ventilation Lining with grass	Stores with 'Sinia B' had lower O_2 O_2 levels were higher in stores with extra ventilation O_2 levels were higher in stores lined with grass
Carbon dioxide (CO_2) in the air within the store	Ventilation Lining with grass	CO_2 levels were lower in stores with extra ventilation CO_2 levels were lower in stores lined with grass Stores with 'Sinia B' had higher CO_2
Temperature (°C)	Damaged roots Ventilation	Temp was 3°C higher in stores with damaged roots in the first 2 weeks of storage ($P<0.01$) Increased ventilation reduced the temp
Relative humidity (RH)	Ventilation	High RH (80-95%) in stores with less ventilation (2 pipes) than in stores with more ventilation (6 pipes; 70-80% RH)>
Respiration rate (RR; ml CO_2/kg/h)	Cultivar	Higher RR for 'Polista' (73.8) compared to 'SPN/O' (45.5) and 'Sinia B' (43.9). 'Polista' is more prone to anaerobiosis in a sealed store

5.3 Yam

Yam is a large genus with several commercially important species, including:

- white yam (*Dioscorea rotundata*),
- yellow yam (*D. cayenensis*),
- water yam (*D. alata*),
- trifoliate yam (*D. dumetorum*),
- Chinese or lesser yam (*D. esculenta*),

- Chinese yam or cinnamon-vine *(D. batatas)*,
- aerial yam *(D. bulbifera),* and
- cush-cush yam *(D. trifida*) (Rees et al., 2012; Ferraro et al., 2016)

D. cayenensis and *D. rotundata* are sometimes pooled into the *D. cayenensis-rotundata* complex due to their similarity (Rees et al., 2012).

The majority (97%) of the world's yam production is in Africa (Table 2) with the main producers being in West Africa which is known as the 'yam belt'. Nigeria alone is responsible for 67% of the world's yam production (FAOSTAT, 2016).

Yam plants produce a single edible tuber which can be stored for a relatively long time (3-8 months), depending the yam variety and maturity. Immature 'milk' yams tended to have a shorter storage life than mature 'ware' yams and are not stored for as long (Bancroft et al., 2005). Once the tubers begin to sprout they become more perishable (Ravi et al., 1996). Yams are susceptible to decay, water loss, insect damage and sprouting (Opara, 2003a; Okigbo, 2004).

Postharvest losses

Coursey (1967) estimated storage losses to be 10-15% after 3 months and 30-50% after 6 months, even under good storage conditions. Bancroft (2001) surveyed storage losses between 1996 and 2000 and estimated 2-3% losses in 'milk' yams and 10-50% losses in 'ware' yams, which tend to be stored for longer periods. AGRA (2014) recorded losses of 60% for yams in Ghana and between 20-30% losses in Nigeria (Figure 14). The reason for these losses are explored in more detail in their study https://agra.org/test/wp-content/uploads/2016/04/establishing-the-status-of-postharvest-losses-and-storage-for-major-staple-crops-2014.pdf.

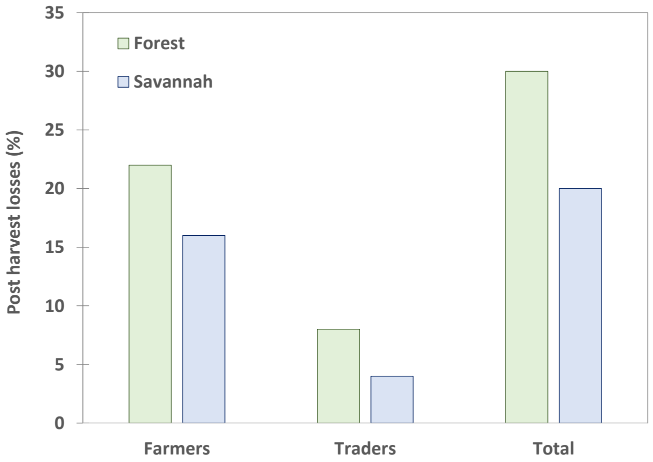

Figure 14. Postharvest losses of yam in forest and savannah regions of Nigeria (redrawn from AGRA, 2014).

Transport from production areas to the cities may result in losses of 2-3% while subsequent handling accounts for 0-40% losses and price discounts of 35-80% (Crentsil & Danso, 1996; Crentsil et al., 1997).

The moisture content of fresh yam varieties ranges from 58 to 80% (Ferraro et al., 2016) and weight loss can be significantly different between the yam species and cultivars (Table 10).

Table 10. Weight loss (%) over 18 weeks of storage of *Dioscorea alata* and *D. esculenta* yam varieties in Trinidad (Coursey, 1967).

Species	**Variety**	**Weight loss (%)**
D. alata	Bottleneck Lisbon	7.3
D. alata	Ginger	7.5
D. alata	White Lisbon	7.7
D. alata	Hunte	9.7
D. alata	Coconut Lisbon	11.3
D. alata	Oriental	21.6
D. alata	Moonshine	32.2
D. esculenta	Chinese	24.6

Benefits of curing

Curing has been successfully used on yams to extend their storage life and reduce postharvest losses. Specifically curing reduces weight loss and decay (both superficial and internal), however it can result in more sprouting of yam tubers (Cooke et al., 1988; Bancroft et al., 2005). The traditional method of curing yams (direct sunlight for 7 days) resulted in 11% weight loss during curing compared to 9% in uncured yams (ambient conditions). After a further 70 days losses at ambient conditions yams cured in the sun had 23% weight loss, 77% sprouting and 7% necrosis versus 36% weight loss, 33% sprouting and 27% necrosis for uncured yams (Been et al., 1977).

Curing immature (milk) 'Pona' yams in a curing chamber at 31-40°C and 85-95% RH for 4 days prior to storage in a barn (28-31°C and 76-100% RH) resulted in less decay and lower water loss than uncured tubers stored in the same conditions (Figure 15). However, these yams were better conserved in a traditional pit store for the first 3-4 months than cured and in a barn. The traditional pit storage system resulted in less decay than curing for 'Pona' but not for 'Onumo' (Figure 16) (Rees & Bancroft, 2003; Bancroft et al., 2005).

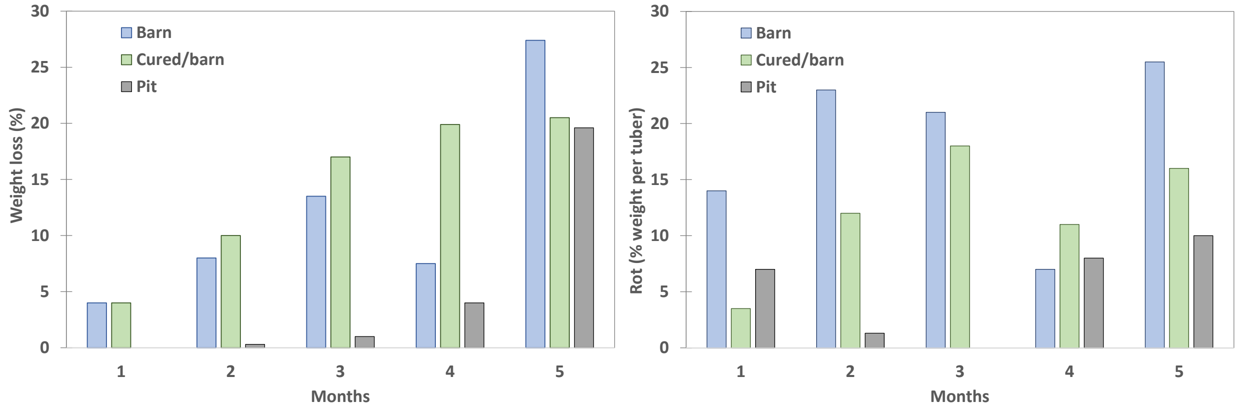

Figure 15. Effect of postharvest conditioning and storage period on weight loss and decay (weight of rotten tuber as percent of total) of 'Pona' milk tubers (*Dioscorea rotundata*) (redrawn from Rees & Bancroft, 2003; Bancroft et al., 2005).

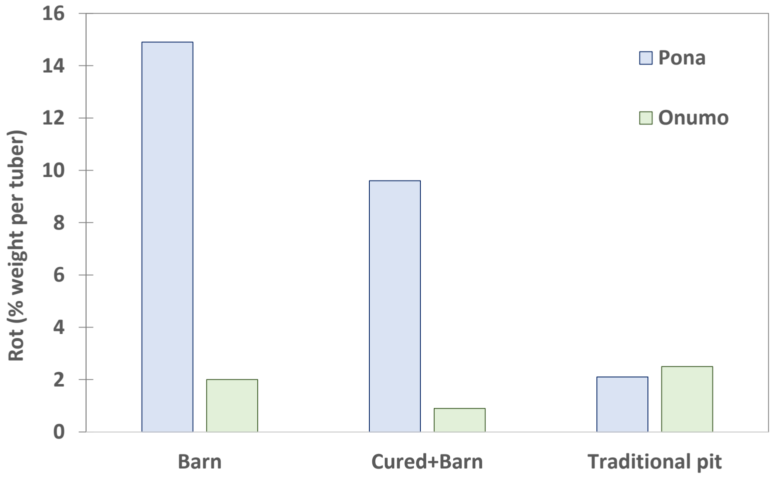

Figure 16. Effect of postharvest conditioning and storage period on decay (weight of rotten tuber as percent of total) of 'Pona' and 'Onumo' milk tubers (*Dioscorea rotundata*) (redrawn from Rees & Bancroft, 2003).

Curing conditions

Traditionally, yams were cured by drying the tubers in the sun for a few days, however the optimum conditions for curing are 29-40°C at 90-95% RH for 5-6 days (Okigbo, 2004). There seems to be agreement on the use of high humidity (>70°C) but the range of suggested curing temperatures (25-40°C) and duration of treatments (2-15 days) varies considerably depending on species. Rees et al. (2012) summarized curing conditions in Table 11.

Table 11. Environmental conditions determined for curing the tubers of different yams (*Dioscorea* spp.) to prolong shelf life (from Rees et al., 2012).

Species	Temperature (°C)	Relative Humidity (%)	Duration (days)	References
D. alata	32	90	4	Gonzalez & Rivera, 1972
D. bulbifera	26-28	high	5-7	Martin, 1974
D. esculenta	26-28	high	5-7	Martin, 1974
D. cayenensis	25-40	95-100	-	Been et al., 1976
D. cayenensis	36-40	91-98	-	Thompson et al., 1977
D. rotundata	25-30	55-82	5	Adesuyi, 1973
D. rotundata	25-40	95-100	-	Been et al., 1976
D. rotundata	26	92	11-15	Nnodu & Nwankiti, 1986

Passam et al. (1976) also found that suberisation occurred within 2-3 days and periderm formation within 4-5 days at 35°C and 85% RH, but at 17°C and 85% RH suberisation occurs after 4 days, and the periderm takes 10 days to form. Rees & Bancroft (2003) and Cornelius et al. (2003) reported that white yam tubers stored at 30°C and 92% RH formed 4, 4.7, 4.8 and 6.25 layers of periderm after 3, 4, 5, and 6 days respectively. In addition, they found that 32°C for 4-5 days was the optimum temperature for curing 'Pona' milk yams based on number of lignified cell layers (Figure 17). At higher temperatures it took at least a day longer to form those layers.

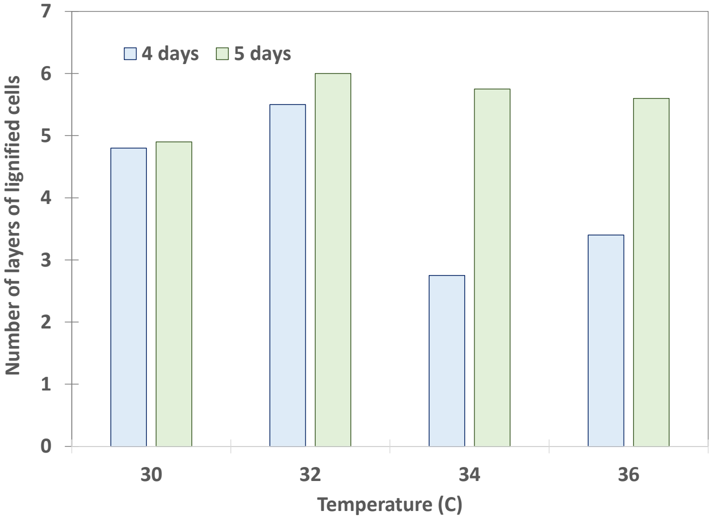

Figure 17. The effect of temperature on the number of lignified cell layers formed in 'Pona' milk yam after curing for 4 and 5 days. Vertical bars represent SE (redrawn from Rees & Bancroft, 2003; Cornelius, 2003).

Been et al. (1977) evaluated curing conditions on white yam tubers (*D. rotundata*) in Jamaica. The proximal end of the tuber was removed for propagation before being held for 7 days in:

A. direct sunlight (standard practice at the time),
B. 26°C and about 66% RH i.e. uncontrolled ambient conditions in a store room,
C. 30°C and 91% RH, and
D. 40°C and 98% RH.

Thereafter all tubers were stored at ambient conditions. Only tubers stored at 30°C and 40°C had cured during the 7 day conditioning period, but after a further 8 days of storage tubers stored in the sun or under ambient conditions showed signs of curing (Been et al., 1997). Yams stored at 40°C and 98% RH had the lowest water loss during curing and storage, no surface mold and minimal necrosis tissue, but they had a high incidence of sprouting (Table 12). The researchers found that 24 hours of curing at 40°C and 98% RH was as effective as longer curing times.

Table 1.2 The effects of curing conditions for 7 days followed by storage at ambient conditions on weight loss, sprouting and storage deterioration of white yam tubers *(D. rotundata).* Figures followed by the same letter were not significantly different (P=0.05) (redrawn from Been et al., 1977).

	After 7 days of curing	**Average over 11 wks**	**After 70 days at ambient conditions**		
Curing conditions	**Weight loss (%)**	**Surface mold score (0-5)**	**Weight loss (%)**	**Sprouting (%)**	**Necrotic tissue (%)**
A. Direct sunlight	11.0 a	0.9 b	22.5 b	77 a	7 b
B. 26C + 66% RH (ambient)	9.1 b	1.0 b	35.5 a	33 c	27 a
C. 30C + 91% RH	2.1 d	1.3 a	36.1 a	50 b	21 a
D. 40C + 98% RH	4.3 c	0.0 c	20.9 b	73 a	6 b

Bancroft et al. (2005) cured milk yam tubers in a field clamp (yams were covered in straw around a bucket of water and covered with a polyethylene sheet which created conditions of 22-31°C and 72-100% RH). While this tended to reduce decay compared to uncured samples uncovered or in plastic bags stored in an improved yam barn (see Henckes et al., 1995 for details on the barn), it was comparable to pit storage (Figure 18). Curing in field clamps with straw attracted termites (Bancroft et al., 2005).

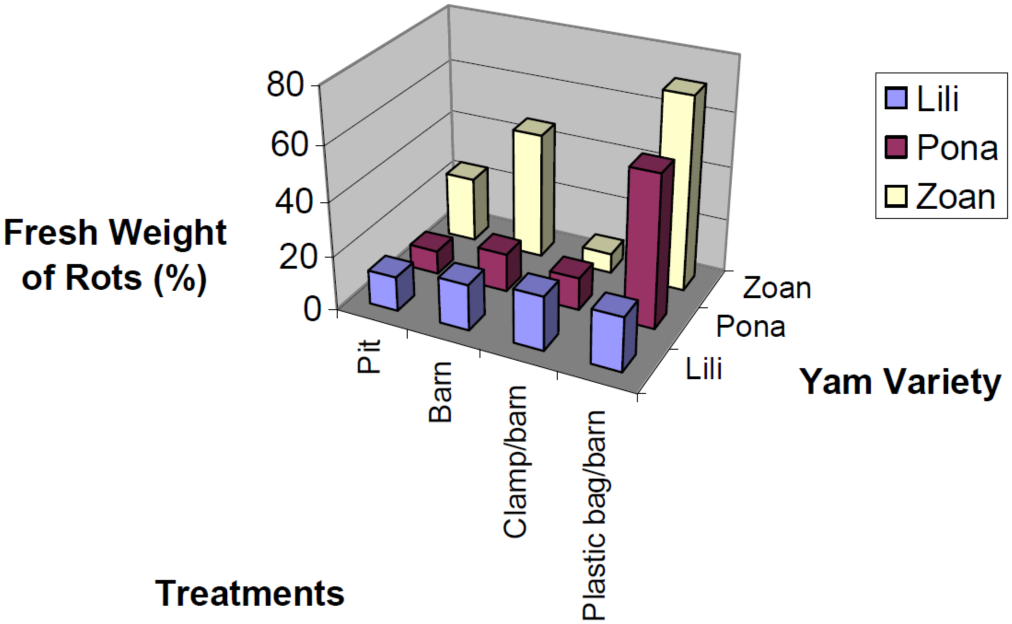

Figure 18. The effect of different curing and storage conditions on decay (weight of rotten tuber as percent of total) of 3 cultivars of immature white yams (*Dioscorea rotundata*) over 5 months of storage. *C*uring was either performed in a field clamp or in plastic bags for 2 weeks prior to transfer to the barn (Rees & Bancroft, 2003; Bancroft et al., 2005).

Glowacz and Rees (personal communication) carried out trials on curing for *D. rotundata* and *D. alata* and, on the basis of resistance to rotting pathogens and resistance to water loss, observed that wound-healing for both species is optimal at 30 - 35°C, RH >90% for 7 days and is inhibited at 40°C.

Storage recommendations

Yams are chilling sensitive and should be stored at 14-16°C and 70-80% RH. Storage life is typically 1-5 months (Rees et al., 2012; Ravi et al., 1996) although they can be stored for as much as 7 months (Cantwell, 2002). Less mature tubers (milk yams) may store better with less ventilation (Rees & Bancroft, 2003a).

Yams have a natural dormancy which affects storage life. The length of this dormancy varies between species and even cultivars (Table 13) (Rees et al., 2012). Once the dormancy breaks the rate of respiration increases as does susceptibility to decay and sprouting (Rees et al., 2012). Storing at 15°C with prompt removal of sprouts was found to improve the eating quality of tubers (Coursey, 1967).

Table 13. Dormancy periods of the major edible yams (Rees et al., 2012; compiled from data by Passam, 1982).

Yam species	Locality	Length of dormancy (weeks)
D. alata	Caribbean	14-16
D. alata	West Africa	14-18
D. rotundata	West Africa	12-14
D. cayenensis	West Africa	4-8
D. esculenta	West Africa	12-18
D. esculenta	Caribbean	4-8
D. trifida	Caribbean	4

Successful storing of yams usually requires proper curing (Chou et al., 2006; Cantwell, 2002) but both cultivar and stage of maturity affect the response of yams to curing and storage. Immature (milk) 'Pona' and 'Lili' yams stored well in pits without curing, while mature (ware) yams and immature 'Onumo' yams (Figure 16) stored better in barns and after curing (Rees & Bancroft (2003) and Bancroft et al. (2005) recommended storing immature 'Pona' and 'Lili' yams in pits for up to 3 months as this resulted in less decay and water loss. However, there is a risk of these yams sprouting and becoming infested with nematodes and termites. In this study curing was for two weeks in either plastic bags or in a humidified clamp (circular pile of yams on straw were covered with a polypropylene and with a bucket of water was placed at the centre of the pile) before being transferred to the improved yam barn (Henckes et al., 1995 for details on the barn; Rees & Bancroft, 2003; Bancroft et al., 2005).

5.4 Taro

Although taro *(Colocasia esculenta***)** originates in Asia, it is more widely produced in both Asia and Africa (Table 2) with Nigeria, being the top producer followed by China. China and Japan have higher yields per hectare than most African countries except Egypt, where taro is irrigated (Ofori, 2003).

Taro produces about 4-10 lateral cormels from a large main corm. Taro is usually only stored for 5-10 days although it can be stored for several months. Postharvest losses in taro are caused mainly due to mechanical damage during harvesting, decay, water loss and sprouting (Opara, 2003b).

Postharvest losses

Reliable data on postharvest losses of taro is very limited. A summary of losses after different storage periods was compiled by Opara, 2003b (Table 14).

Agbor-Egbe and Rickard (1991) measured 60% decay and 10% sprouting in over-mature 'Fulani' corms stored at 30°C and 85% RH for 32 days, while those stored at only 45% RH had 14% decay and no sprouting. 'Ekona' had 55% decay and 15% sprouting and 'C-6' had 55% decay and no sprouting after 32 days at 30 °C and 85% RH.

Table 14. Storage losses of taro corms under traditional storage methods in ambient conditions (adapted from Opara, 2003b).

Length of storage	Nature of losses
5-10 days	became unfit for human consumption
1-2 weeks	became unfit for human consumption
2 weeks	decayed rapidly
6 weeks	28% fresh weight loss & 53% decay
8 weeks	50% loss
12 weeks	more than 30% wastage
20 weeks	95% loss

Curing conditions

Rickard (1981) reported that the best conditions for wound healing in taro was 34-36°C with 95-100% RH. The low weight loss in 'Fulani', 'Ekona' and 'C-6' taro corms after 14 days under tropical ambient conditions (24-29°C with 86-98% RH) was attributed to curing (Agbor-Egbe and Rickard, 1991).

Storage recommendations

Taro is chilling sensitive and quality can be adversely affected when stored at 7°C and lower. Storage at 7-13°C and 85-90% RH can extend the storage life to 4 months (Cantwell, 2002; Opara, 2003b). Opara 2003b summarized published storage conditions and duration (Table 15).

Table 15. Conditions and duration of storage of taro corm (adapted from Opara, 2003b).

Temperature (°C)	Relative humidity (%)	Length of storage (weeks)
4.4	-	14
7.2	70-80	13
7.2	85-90	17-21.5
7-10	85-90	16-20
10	-	up to 26
11-13	85-90	20
12	90	20
13.3	85-90	6-17
20	60	2-4

Sajeev et al. (2004) stored freshly harvested taro cormels under ambient conditions (32-45°C, 30-50% RH), in an evaporatively cooled chamber (EC; 3×3×3 m with a double wall of thick brick, sand between the walls and a drip irrigation system to keep the walls wet; 26-34°C, 59-92% RH) or in a refrigerator at 10°C and 65% RH. Although refrigerated storage resulted in the lowest weight loss over 20 days of storage, the EC room was better than ambient conditions (Figure 19). Under these conditions the EC room would have provided acceptable conditions for curing as well as storage.

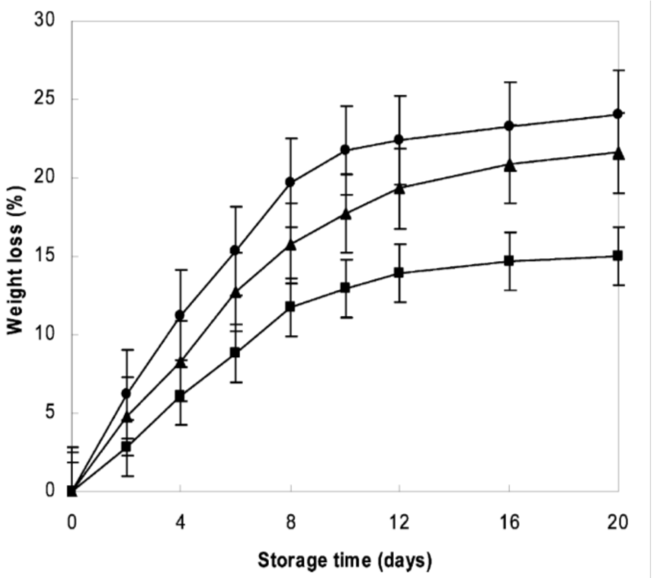

Figure 19. Effect of storage conditions on weight loss (%) of taro cormels stored at ambient conditions (●), in an evaporatively cooled chamber (▲) or in a refrigerator at 10°C (■) (Sajeev et al., 2004).

5.5 *Xanthosoma*

According to FAOSTAT 100% *of Xanthosoma* spp. (yautia or tannia) production is in the Americas (Table 2), with Cuba being the top producer. However, Bikomo Mbonomo & Brecht (1991) stated that it is also a dietary staple in Asia and Africa.

The classification of this aroid crop is unclear and while there may be four species (*X. atrovirens*, *X. caracu*, *X. nigrum* [X. *violaceum*], and *X. sagittifolium), X. sagittifolium* tends to be used for all cultivars (FAO, 2013).

Xanthosoma matures 6-13 months after planting. It has a main underground stem or corm, from which about 4-10 cormels (15-22 cm in length) develop. The cormels can be stored for several weeks at room temperature and several months at lower temperatures. Water loss and decay are the most important causes of losses of stored *Xanthosoma* (Bikomo Mbonomo & Brecht, 1991; Opara, 2003b).

Postharvest losses

After 6 weeks of storage under ambient conditions *Xanthosoma* cormels had a weight loss of 35% and 40% decay (Passam, 1982). Praquin and Miche (1971) measured losses from decay of 50% after 2 months of storage under ambient condition in Cameroon and 95% after 5 months.

Benefits of curing

Passam (1982) found that curing *Xanthosoma* for 5 days at 35°C and 95% RH prior to storage for 6 weeks (27-32°C) reduced weight loss by 12% and decay by 10%. Curing *Xanthosoma* cormels at 30°C or 35°C and 95-100% RH for 7 days significantly reduced defects (decay, sprouting, toughness, and shrivel) and increased the percent marketability after storage at 25°C and 75% RH, compared to curing at 40°C or not curing (Figure 20). Weight loss during curing (first week) increased with increasing temperature, but after an additional 3 weeks of storage overall weight loss was lower in cormels cured at 30°C (12.2%), or 35°C (12.8%) than those cured at 40°C (14.5%) or 25°C (15.8%) (Figure 20) (Bikomo Mbonomo & Brecht, 1991).

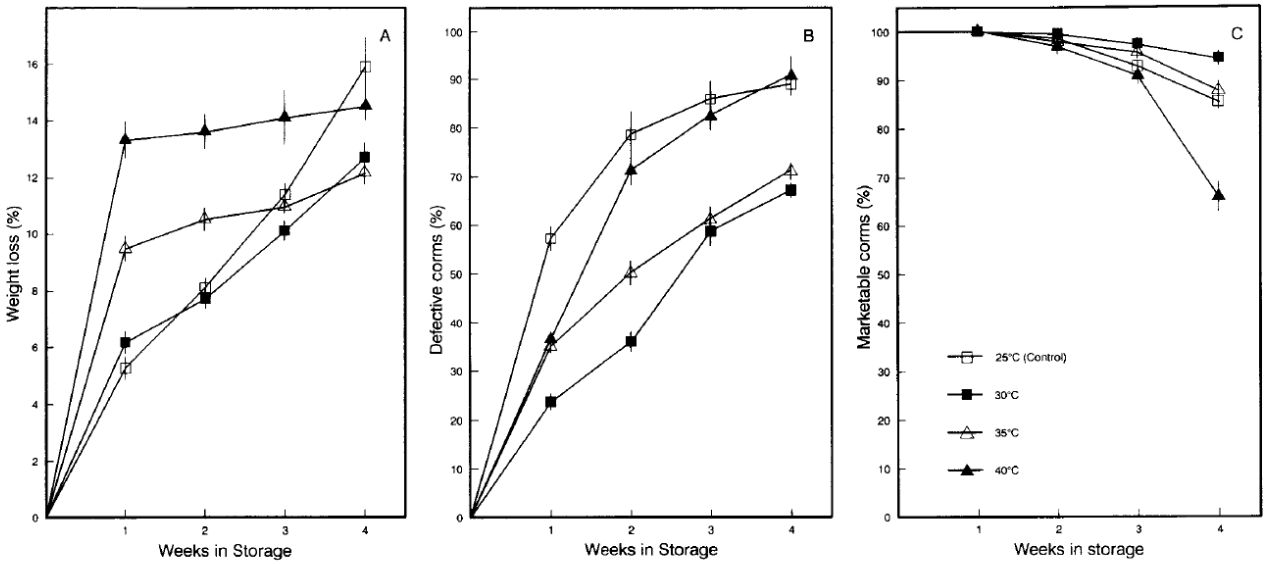

Figure 20. Weight loss (A), defects (B) and marketability (C) *of Xanthosoma* cormels after curing for 7 days at 30, 35 or 40°C and 95-100% RH, and subsequent storage at 25°C and 75 + 5% RH. Controls were stored at 25°C and 75% RH throughout (Bikomo Mbonomo & Brecht (1991).

Curing reduced the respiration rates of *Xanthosoma* cormels directly after 7 days of curing (30°C; 95% RH) and when measured after two weeks of storage (compared to uncured cormels). Cured *Xanthosoma* had slightly lower respiration rates and lower ethylene production than uncured cormels when bruised (Bikomo Mbonomo et al., 2015).

The respiration rate of 'Medere Blanc' cormels after 32 days was greater at warmer conditions as expected. Weight loss at 30°C and 85% (curing conditions) was relatively low especially compared to storage at 15°C and 45% RH or even 85% RH (Table 16) (Agbor-Egbe & Rickard, 1991).

Table 16. Mature 'Medere Blanc' cormels stored for 32 days at either 15 or 30°C and either 45 or 85% RH (compiled from Tables 3 & 4 in Agbor-Egbe & Rickard, 1991).

Temperature (°C)	**Relative humidity (%)**	**Respiration (ml CO_2/kg/h)**	**Weight loss (%)**
15	45	0.9	6.1
15	85	0.4	4.3
30	45	10.5	12.9
30	85	8.6	5.1

Curing conditions

Bikomo Mbonomo & Brecht (1991) found that 30-35°C and 95-100% RH were the best curing conditions. Five to eight layers of cork cells were produced in 7 days at 30°C or 35°C, but no cork cell production was observed at 25°C or 40°C. Natural curing can take place when the cormels are stored moderate temperatures (24-29°C) and 86-98% RH (Agbor-Egbe & Rickard, 1991).

Storage recommendations

Storage at temperatures below 7-10°C induced chilling injury (surface pitting, flesh discoloration and decay) in *Xanthosoma*. Cormels stored at 7-10°C avoided the development of chilling injury and had the longest storage life (Table 17). Increasing the storage temperature to 15°C compromised storage life, however it is not uncommon for *Xanthosoma* to be stored at ambient conditions (Bikomo Mbonomo & Brecht, 1991; Ravi et al., 1996; Opara, 2003).

Table 17. Conditions and duration of storage of *Xanthosoma* cormels (Opara, 2003b).

Temperature (°C)	Relative humidity (%)	Length of storage (weeks)
7	80	17.1-18.6
7.2	80	18
7-10	80	16-20
15	85	5-6

5.6 Potato

Potato (*Solanum tuberosum*) is one of the only starchy root crops grown throughout the world, including in temperate zones (Table 2). China has the highest production, followed by India. While it is second in terms of area harvested, potato yields are higher than cassava (FAOSTAT, 2016).

Curing, or wound healing, was optimized in potato and since then, has been applied to the tropical root crops. As a result of good curing conditions followed by controlled storage environments, potatoes can be stored for up to a year (Cantwell & Kasmire, 2002).

Curing conditions. Potatoes are usually cured at 7-15°C and high relative humidity (85-95%) with ambient atmospheres. These temperatures are warm enough for curing to occur within 14 days but can delay microbial growth and excessive water loss associated with curing at higher temperatures (Table 18).

Table 18. Effect of temperature on the wound healing process of potatoes (Cantwell & Kasmire, 2002, adapted from Burton, 1982).

Temperature		Days to form	
(°C)	(°F)	Suberin	Periderm
2	36	7-8	not formed
5	41	5-8	10
10	50	3	6
15	59	2	3
25	77	1	2

Storage recommendations

Potatoes are stored at temperatures ranging from 7-20°C and high relative humidity (95%) depending on their intended use. Table potatoes are stored at 7-10°C, and potatoes processed directly into French fries (chips) or chips (crisps) are stored at higher temperatures to prevent conversion of starch to sugar which resulted in darkening during processing (Cantwell & Kasmire, 2002).

Conclusions

Curing has been used successfully to extend the storage life of potato, and has potential to do the same for the tropical root crops. This review has summarized the knowledge on curing so that it can be adapted by growers and handlers of tropical root crops, especially in developing countries. Indigenous materials and structures can be used to cure these crops, making it cost effective and easy to apply in the field directly following the harvest or whenever crops are ready to be stored on small farms.

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Appendix 1. Useful websites

Sweet Potato Knowledge Portal: http://www.sweetpotatoknowledge.org/

Manual available for download: Stathers et al., 2013. Everything You Ever Wanted to Know about Sweetpotato. http://www.sweetpotatoknowledge.org/files/everything-you-ever-wanted-to-know-about-sweetpotato-tot-manual-volume-1-2/

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Building a ZECC https://www.youtube.com/watch?v=enOjVc-kN7Q

Charcoal cooler https://www.youtube.com/watch?v=ipqvedQW6a8

Appendix 2. Curing and Storing of Starchy Roots Crops

What root crops can be cured?

- sweet potato roots (*Ipomoea batatas)*,
- cassava roots (*Manihot esculenta)*
- potato tubers (*Solanum tuberosum)*,
- yam tubers (*Dioscorea* species),
- taro corms (Colocasia),
- tannia or yautia cormels (*Xanthosoma sagittifolium*).

What is curing?

Is exposing root crops to warm and humid conditions for a few days to a few weeks to allow the wounds to heal and changes to take place that make the root more resistant to water loss and decay (rotting).

What are the benefits of curing?

Curing has been shown to:

- reduce water loss,
- reduce decay (rotting),
- increase storage time from days or weeks to months,
- reduce the severity of discoloration (postharvest physiological disorder) in cassava.

Curing recommendations:

Commodity	**Temperature (°C)**		**Relative Humidity (%)**	**Duration***
	Optimum range	**Acceptable range**	**Optimum range**	**(days)**
Cassava	30-35	25-40	80-95	7-14
Potato	10-15	7-15	85-95	10-14
Sweet potato	28-30	30-32	85-90	3-10
Taro	34-36	30-36	85-98	3-5
Yams	30-35	25-35	85-90	4-15
Xanthosoma	30-35	25-35	90-98	5-10

*Curing takes longer outside of the optimum temperature range and at lower RH.

How do you evaluate curing?

A simple test for curing is to feel the peel of the crop. If the peel is firmly attached and does not 'slip' when pressed sideways with your thumb, the root has fully cured.

What are the recommendations for storage of these root crops?

- Storage recommendations can vary between different species (as in the case of yams) and between different cultivars.
- Rigorous sorting to remove damaged roots before storing is necessary for medium to long term storage.
- Low relative humidity and fluctuating temperatures will result in higher water loss.

Storage recommendations and typical storage durations associated with different storage recommendations are summarized below:

Commodity	Temperature (°C)	Relative Humidity (%)	Storage duration
Cassava	ambient		2-4 days
	5-8	80-90	2-4 weeks
	0-5	85-95	1-2 months
Potato			
Fresh	4-12	90-98	5-10 months
Processing (fries/chips)	7-15	90-98	5-10 months
Sweet potato	ambient		1-2 weeks
	13-15	85-95	4-7 months
Taro	ambient		2-4 weeks
	7-10	85-90	4 months
Yams	27-30	60-70	3-5 weeks
	14-16	>95	1-7 months
Xanthosoma	ambient		3-6 weeks
	7-15	80-85	20-24 weeks

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